AD-784 406

CHARACTERISTICS OF THE NAVY LARGE FLOATING SHOCK PLATFORM

E. W. Clements

Naval Research Laboratory

Prepared for:

Naval Ship Systems Command

15 July 1974

DISTRIBUTED BY:

NTIS

National Technical Information Service
U. S. DEPARTMENT OF COMMERCE
5285 Port Royal Road, Springfield Va. 22151

AD784406

NRL Report 7761

Characteristics of the Navy Large Floating Shock Platform

E. W. CLEMENTS

Applied Mechanics Branch
Ocean Technology Division

July 15, 1974

NAVAL RESEARCH LABORATORY
Washington, D.C.

Approved for public release; distribution unlimited

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER NRL Report 7761	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) CHARACTERISTICS OF THE NAVY LARGE FLOATING SHOCK PLATFORM		5. TYPE OF REPORT & PERIOD COVERED Interim report on a continuing NRL problem 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) E. W. Clements		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Research Laboratory Washington, D.C. 20375		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS F02-37
11. CONTROLLING OFFICE NAME AND ADDRESS Department of the Navy Naval Ship Systems Command Washington, D.C. 20360		12. REPORT DATE July 15, 1974 13. NUMBER OF PAGES 46
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Shipboard shock
Mechanical shock
Shock simulation
Shock testing
Shock machines
Shock platforms
Large Floating Shock Platform (LFSP)

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The shock environment produced by an underwater explosion is hazardous to vital shipboard equipment. For many years the Navy has pursued a broad research, test, and evaluation program aimed at ensuring that the fighting ability of Navy vessels not be impaired by combat conditions. An important tool in this program has been the Navy's family of devices for generating shocks resembling those that might occur on shipboard. These devices provide controlled tests for shipboard components weighting up to 60,000 lb. (over)

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE
S/N 0102-014-6601

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

20. This report describes the characteristics of the most recent addition to this family, the Large Floating Shock Platform (LFSP), which extends the testing capacity to items weighing up to 400,000 lb.

CONTENTS

CHARACTERISTICS OF THE NAVY LARGE FLOATING SHOCK PLATFORM

INTRODUCTION

Purpose

This report briefly describes the operation and shock characteristics of the Large Floating Shock Platform (LFSP) as observed during the calibration test series. It is anticipated that the LFSP will be specified by future editions of MIL-S-901 [1] as the shock-test device to be used for items weighing from 40,000 to 400,000 lb. The procedures for specification tests will be prescribed by the appropriate codes of the Naval Ship Systems Command.

Background

Before the introduction of large noncontact weapons, the shock environment on board a ship was localized. The shock could result from hits by enemy weapons or from firing the ship's own guns, and while locally very severe had little effect at some distance. Some types of equipment were virtually immune to shock damage because of their location, whereas others were regularly exposed to severe shock. This situation was changed by the emergence of large weapons, since a large weapon detonated at a distance produces a shock that affects the entire ship. Equipment and systems that had previously survived combat without difficulty were reduced to scrap by these widespread shocks. The remedy was a program including analysis of equipment failure modes, measurement of shipboard shock and environments, development of shock simulation devices, and development of techniques for design and testing. This program continues as the characteristics of weapons, equipment, and ships evolve, along with the mixture of ships that make up a combat force.

The Navy basic shock specification (MIL-S-901) applies to virtually all shipboard equipment. This specification requires the direct testing of free-standing equipment or system components on one of three standard machines, according to weight. These machines are the Navy High-Impact Shock Machine for Lightweight Equipments (LWSM) (up to 400 lb), the Navy High-impact Shock Machine for Mediumweight Equipments (MWSM) (250-6,000 lb), and the Navy Floating Shock Platform (FSP) (6,000-60,000 lb) [2]. Equipment and system components which because of weight or size cannot be tested are to be designed or evaluated using specified dynamic-analysis methods. The direct tests are of a universal nature, since most of the items in this weight range may be installed in many locations on a variety of ships. The specified analysis procedures are more individualized, since very large items are usually installed in one general area of a ship and in only a few classes of ships. In view of this, different design inputs are

Note: Manuscript submitted May 7, 1974.

specified depending on where in the ship the item is to be installed and whether it is to be used aboard surface ships or submarines.

While shock tests with ships demonstrated that this program of specified test or analysis is successful, it required expansion for two reasons, First, it is obviously desirable to test directly any shipboard item, regardless of its size or weight. Second, the data on which the specified test and design procedures are based were accumulated from shock tests of light to moderate severity against small ships and of light severity against large ships. It was realized that extending this data base by measurements on large ships under shock attacks of moderate to high severity would provide guidance as to how a device for testing large items should be designed and operated and also provide a check on the validity of extrapolations incorporated in the existing test and design specifications. Operation Dive Under was undertaken to meet these needs. Phase I entailed the at-sea shock tests of the heavily instrumented ex-USS *Atlanta* (IX304) in the summer of 1970. Phase II consisted of the design, construction, and calibration of the Large Floating Shock Platform (LFSP), a device for shock testing shipboard items in the weight range of 40,000 to 400,000 lb.

DESCRIPTION

The LFSP was designed by the West Coast Shock Facility (WCSF), Hunters Poi Naval Shipyard, San Francisco, Calif., in collaboration with the Naval Research Laboratory (NRL), Washington, D.C. It was built by Todd Shipbuilding Corp. at Alameda, Calif., and delivered to WCSF in February 1973.

As its name implies, the LFSP (Fig. 1) is basically an enlarged version of the Floating Shock Platform (FSP). It is a rectangular, flat-bottomed barge 50 ft 5 in. by 30 ft 2 in. It weighs about 500,000 lb and draws (empty) 5 ft 2 in. The bottom, ends, and sides are 62.1-lb (1.5-in.-thick) HTS plate, and the 12-ft-high sides and ends are topped by a 6-ft bulwark of 15-lb (0.375-in.) HTS plate. With a total added load of 500,000 lb, the LFSP would draw approximately 10 ft 4 in., leaving a freeboard of 1 ft 8 in. on the shock-resistant sides, plus the 6-ft bulwark. If 20% of this total load is for foundations and fixtures, it appears that test items weighing up to 400,000 lb could be accommodated comfortably. As with the FSP, it is essential that the weight distribution of the installation not interfere with stability.

Unlike the FSP, the LFSP has no inner bottom: it has a similar cellular bottom structure with 6 longitudinal and 11 athwartship stiffeners, 32 in. high and made of 40.8-lb HTS plate, but the stiffeners are capped by HTS flanges 8 in. wide and 3 in. thick, which form a mounting plane. The unit cell is roughly 4 ft square. The LFSP is covered by a 3-section semicyclindrical canopy, each section of which consists of a 12-in. mild steel I-beam covered by corrugated fiber-glass panels. The forward and aft ends are filled with expanded metal sheet covered by trapaulins. The available working space within the LFSP is roughly 48 ft long, 28 ft wide, and 34 ft high to the center of the canopy.

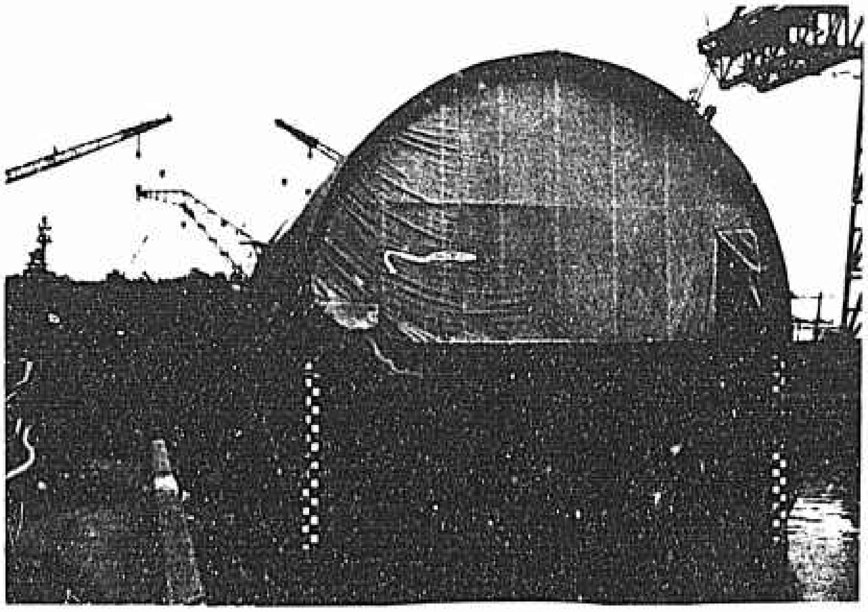

Fig. 1 — Navy Large Floating Shock Platform (LFSP)

MOUNTING ARRANGEMENTS

Test items are installed in the LFSP by means approximating as closely as possible those used aboard ship. In most cases this will probably be done by welding or bolting the actual shipboard foundations to the LFSP mounting plane. In some cases it may be necessary to build a subsidiary structure to adapt the shipboard foundations to the flat mounting surface of the LFSP stiffener flanges.

OPERATING PROCEDURE

The operating procedure (see Appendix A) is similar to that used with the FSP; the loaded LFSP is moved into position in the shock basin, and charges are detonated at specified locations with respect to it. The differences are matters of detail. The larger size of the LFSP requires a longer standoff in order to avoid an unseemly variation in shock severity over its area, which in turn requires a larger charge to attain the desired shock severity. With a larger charge, it is advisable to minimize coupling of the shock energy into the surrounding shore area by allowing the bubble to vent on its first expansion. Because of these considerations, a 300-lb charge is used with the LFSP, detonated at a depth of 20 ft (Fig. 2), compared to a 60-lb charge at 24-ft depth for the FSP.

CALIBRATION OF SHOCK OUTPUTS

To be a useful tool for research or testing, a device must be calibrated. It must be possible to control its performance or at least predict how that performance will change as operating conditions change. The information needed to do this is obtained by setting up representative combinations of the variable factors of its operation and measuring its

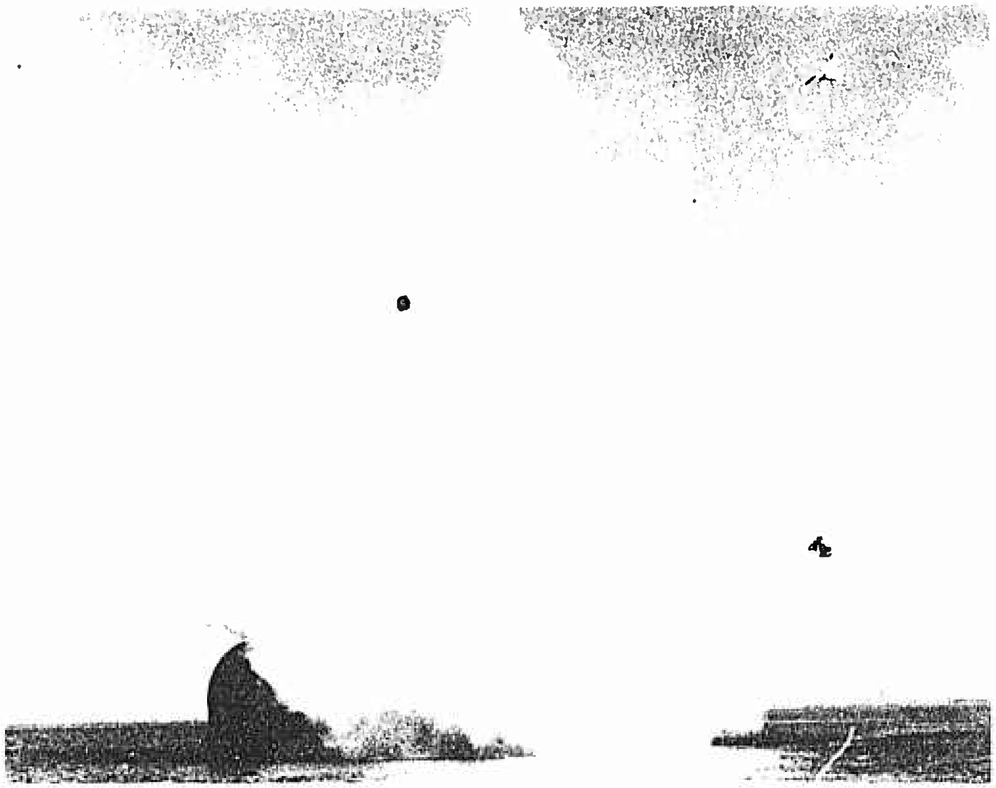

Fig. 2 — A side shot at 45-ft standoff

performance for each combination. The most important variable factors in the operation of the LFSP are the size of the charge, its location relative to the LFSP, and the nature of the test load. As remarked previously, the size of the charge is essentially predetermined by the requirement that it be fairly large and by legal and environmental limitations that it not be too large. The charge depth is also largely predetermined by available water depth and by legal and environmental considerations. The nature of the test load (weight, size, dynamic properties, etc.) constitutes a test parameter rather than a control variable and should be restricted as little as possible. The two variable factors remaining are used as test control variables. These are the charge standoff, i.e., the horizontal distance separating the charge from the closest point of the LFSP, and the orientation (in plan view) of the charge in relation to the LFSP.

CALIBRATION OF TEST ARRANGEMENT

Prior to acceptance by the Navy, the LFSP as received was subjected to a series of tests to ensure that its construction was satisfactory. Scaling by shock factor* indicated that a standoff of 45 ft would produce a shock severity comparable to that produced aboard the FSP with the closest shot specified by MIL-S-901. It is unlikely that this level

*Shock factor is a parameter which has been found to relate to damage in shipboard equipment and is in general use as a measure of the severity of shock caused by underwater explosions. It is a function of the test geometry and size of the charge.

Table 1
Shot Schedule for LFSP Calibration Test

Shot No.	Date (1973)	Near Side	Standoff (ft)	Added Load 10^3 lb
1	Feb 28	Port	70	0
2	Mar 1	Port	55	0
3	Mar 2	Port	45	0
4	Mar 5	Stern	45	0
5	Mar 6	Starboard	45	0
6	Mar 7	Bow	45	0
7	May 7	Port	120	112.6
8	May 9	Port	70	112.6
9	May 10	Port	45	112.6
10	May 16	Stern	45	112.6
11	May 17	Port	70	176.9
12	May 18	Port	45	176.9
13	May 22	Port	45	176.9
14	May 23	Stern	45	176.9

of severity will be exceeded for normal testing, so shots at 45-ft standoff were made against all four sides of the LFSP. To provide a graduated buildup to full shock severity, preliminary shots at 70 ft and 55 ft were made against the port side. This acceptance test series is included in Table 1 as Shots 1 - 6.

The test load was then installed for the rest of the test series. The load consisted of an FSP mounted on three strongly gusseted steel plates, one about 2 ft in from each end of the FSP and one at its midpoint. Each was 16 ft long at the top, where it matched the FSP bottom, and 20 ft long at the bottom, where it attached to the LFSP mounting plane. To permit access below the FSP, the plates were 18 in. high, and their thickness was 7/8 in. Gussets, also 7/8 in. thick, were added to the mounting plates at each intersection of LFSP longitudinal and athwartship stiffeners. These were 1 ft long at the top (FSP) and 2 ft long at the bottom (LFSP). Each mounting plate was so gusseted on both sides at four locations. The load arrangement is shown in Fig. 3.

Centered within the FSP was a single-degree-of-freedom system (SDOF) which had been built for an earlier series of experiments. This was designed at the then David Taylor Model Basin, now the Naval Ship R & D Center (NSRDC), Carderock, Md., and consisted of a 5,000-lb concrete block supported by semicylindrical steel springs on all four sides. The SDOF's other modes were considerably higher in frequency than the simple vertical translation mode at 30 Hz. In addition to the SDOF, the FSP contained angle-iron frames

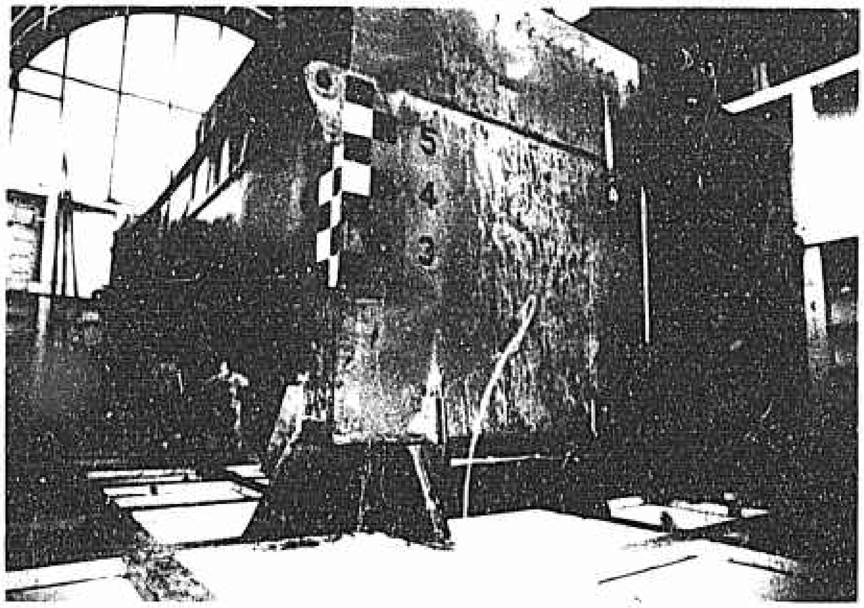

Fig. 3 — The FSP installed as a test load

along its starboard side. Packaged racks of recording and measurement electronics were hung from these by shock cord.

After this test load had been installed, the draft of the LFSP had increased to 6 ft 4 in., implying a total added load of 112, 600 lb. A test series of four shots (Table 1, Shots 7 - 10) was conducted with this load condition. The space between the FSP deck and bottom was then filled with fresh water to provide a heavier load. After this the draft of the LFSP was 7 ft, or a total load of 176, 900 lb. An additional series of four shots was conducted (Table 1, Shots 11 - 14).

INSTRUMENTATION

The LFSP was instrumented for measurement of motion and strain at selected parts of its structure. With one exception, the motion transducers were piezoresistive accelerometers in shock-mitigating housings. The output signals from these were integrated electronically before being recorded. One strain-gage accelerometer was used to measure the response motions of the SDOF mass. Its output was amplified and recorded directly as acceleration. In addition to the motion transducers, strain gages were installed on the LFSP shell plating, central athwartship stiffener, and central FSP mounting plate. Details of the packaged accelerometers and the electronics used for all transducers are given in Ref. 3.

The motion transducers were placed to measure input velocities to the FSP and SDOF, response velocities of the FSP, and response acceleration of the SDOF. The strain gages measured strain in the LFSP bottom plating near the central athwartship stiffener, in the stiffener itself, in the portside shell plating adjacent to it, and in the FSP mounting plate attached to it The strain-gage bridges were arranged to read the total strain along

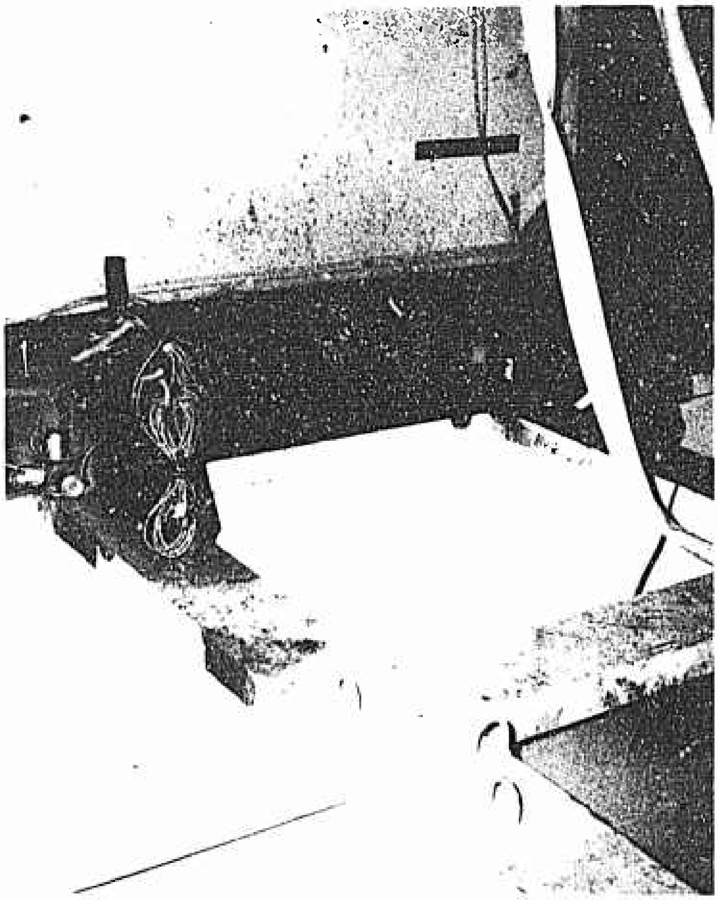

Fig. 4 — Typical motion transducer installation: AV 200 V,A,F, (left) and AV 202 V,A (right) viewed from LFSP port, looking aft

their sensitive axes in the surface to which they were attached; those on the vertical surfaces had their sensitive axes set vertical, those on the bottom plating across the beam of the LFSP. A few typical installations are shown in Figs. 4-9. A complete description of the types and locations of the transducers is given in Fig. 10 and in Appendix B.

Apart from the transducers, the complete measurement and recording system (signal-conditioning electronics, power supplies, magnetic-tape recorders, etc.) was contained in unitized packages supported from steel frames by shock cord. For the acceptance test series (Table 1, Shots 1 - 6) only the velocity transducers on the shell plating of the bottom were installed, and a single electronics package sufficed (Fig. 11). For the remainder of the series, with the FSP in place as a test load and with substantially more instrumentation, two electronics packages were necessary (Fig. 12). Firing and control circuitry was in one of the packages, the principal components being a high-voltage power source which fired the charge and a sequence controller which operated the tape recorders and applied voltage to the charge. Both were hard-wired to a control station on shore from which they could be started and stopped as desired. All electrical power was furnished from shore in the form of 440-V, 3-phase, and stepped down to 110-V, 1-phase, by a shock-isolated transformer.

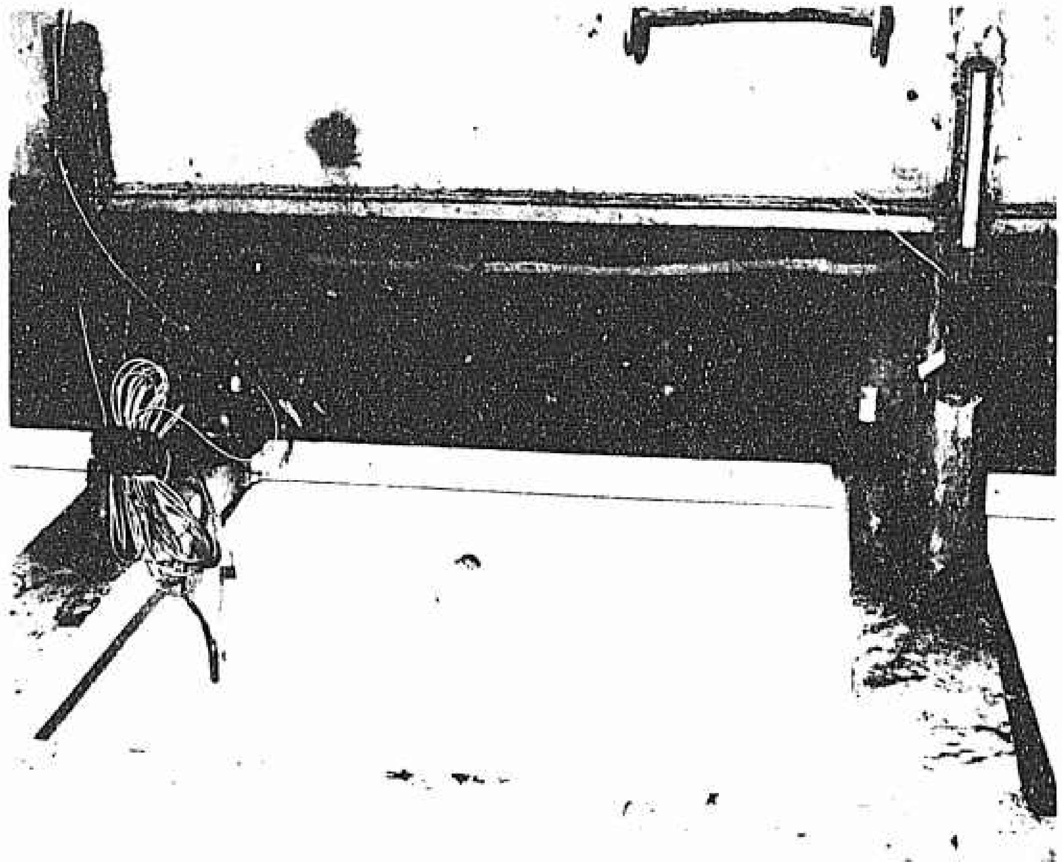

Fig. 5 — Typical motion transducer installation: AV 205 V (right) and AV 207 V,A (left) viewed from LFSP stern, looking forward

Immediately after each shot, the tapes were removed from the recorders and taken to the analysis station, where the signals were played back on an oscillograph. Each channel was played back individually in optimized format using an NRL Shock Signal Integrator [4]. This device uses cascaded integrators. It can provide properly scaled outputs, proportional to the raw input signal and its first two integrals, which can be recorded simultaneously in "three-parameter" format. For the accelerometer signal, the oscillogram format was scaled input (acceleration), first integral (velocity), and second integral (displacement). For the velocity signals, the format was scaled input (velocity) and first integral (displacement), and for the strain signals, scaled input (strain) only. Some of the motion signals were also processed on a developmental analog device to provide shock spectra.

SHOCK OUTPUT WAVEFORMS

There is a large degree of uniformity in the character of the motions measured at various input points. The input waveforms are most strongly modified in shape by the orientation of the measurement and in magnitude by the location of the measurement.

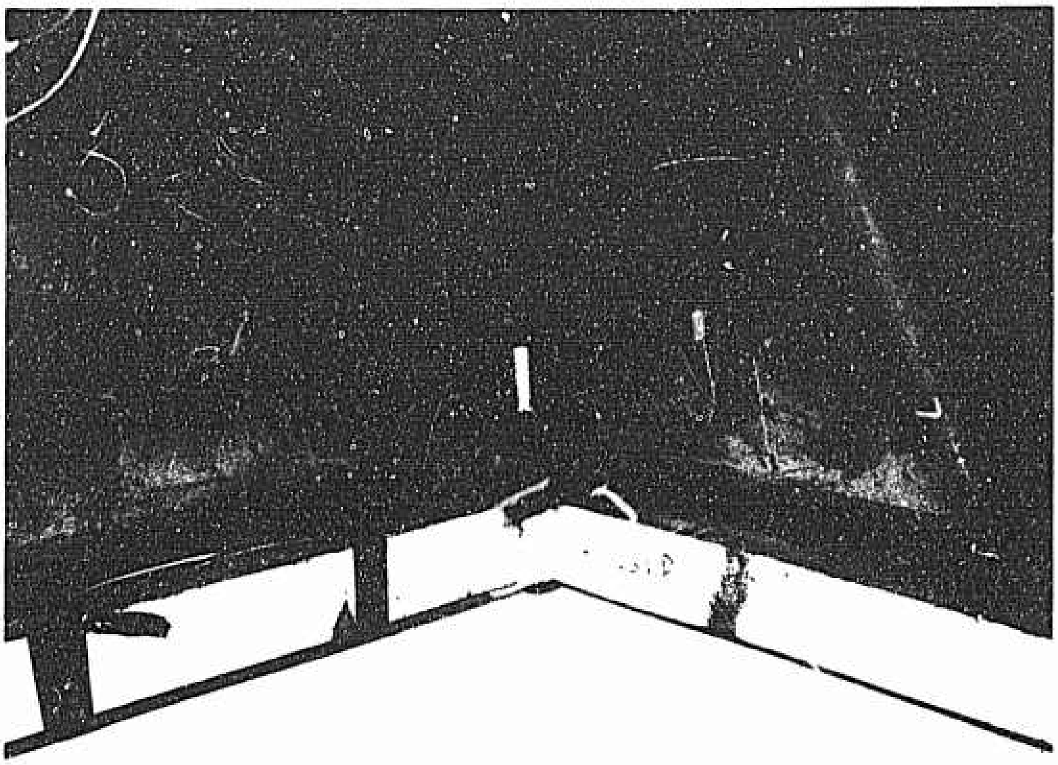

Fig. 6 — Typical motion transducer installation: AV 203 V,A, viewed from midships, LFSP starboard side, looking to port

This is the case with the response motions also, since the response measurements are taken mostly on structurally similar parts of the FSP.

The measurement locations fall in three broad categories: those on the shell plating of the LFSP, those at the inputs to the FSP, and those at the response of the FSP. In each category, the closer the point of measurement is to the charge, the higher the peak velocity, the extent of the variation depending on both the category of the location and the orientation of the measurement.

LFSP Velocity Waveforms

The vertical and horizontal-parallel* velocities show sharp rises (1 ms) and slow declines (100 ms) embellished by structural frequencies (up to 1 kHz). The horizontal-transverse† velocities consist of the structural frequencies modulated in amplitude by a moderately fast rise (10 ms) and slow decline (300 ms) (Fig. 13).

*The horizontal direction parallel in plan view to the line between the charge and the closest point of the LFSP—athwartship for a side shot, fore-and-aft for an end shot.

†The horizontal direction perpendicular in plan view to the line between the charge and the closest point of the LFSP—fore-and-aft for a side shot, athwartship for an end shot.

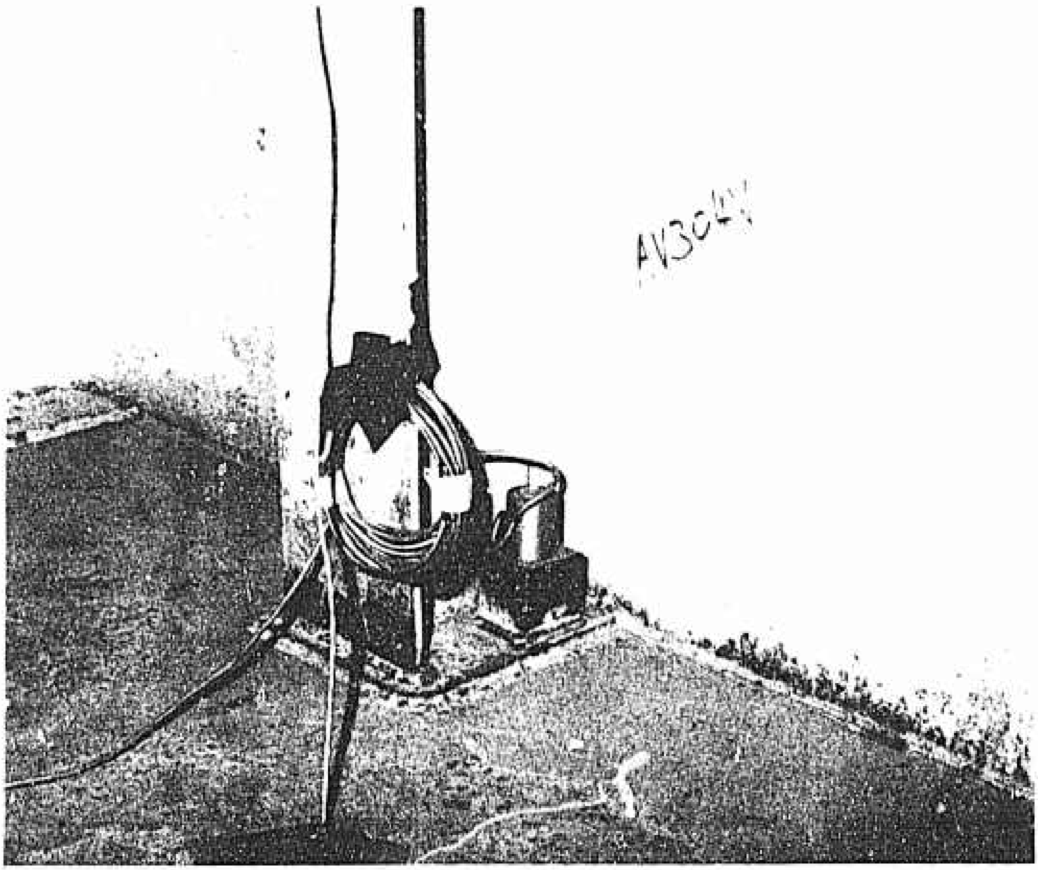

Fig. 7 — Typical motion transducer installation: AV 304 V viewed from midships, FSP port side, looking to port

Effects of Measurement Location

The variation in peak velocities for a particular shot is least in the measurements on the shell plating of the LFSP bottom, where the highest (vertical) peak is 1.65 times the lowest. This is partly because of 2-kHz low-pass filtration by the shock-mitigating transducer housings, which tend to render the measured velocity peaks lower and more uniform by eliminating much of the high initial spike of velocity reported to be characteristic of plating motions.

For purposes of defining the shock environment prevailing aboard the LFSP, the velocities measured at the FSP inputs are most significant. Here the short, high initial spikes have been softened by the intervening structure, and the velocity waveforms no longer have a substantial energy content at frequencies beyond the transducer passband. The peak velocities measured at these locations are generally lower than those taken on the shell plating of the LFSP, and the variation in them is greater, the largest being 1.75 times the smallest for a single shot. On the average, peak velocities at the FSP inputs were 0.85 times the peak velocities on the shell plating of the LFSP bottom.

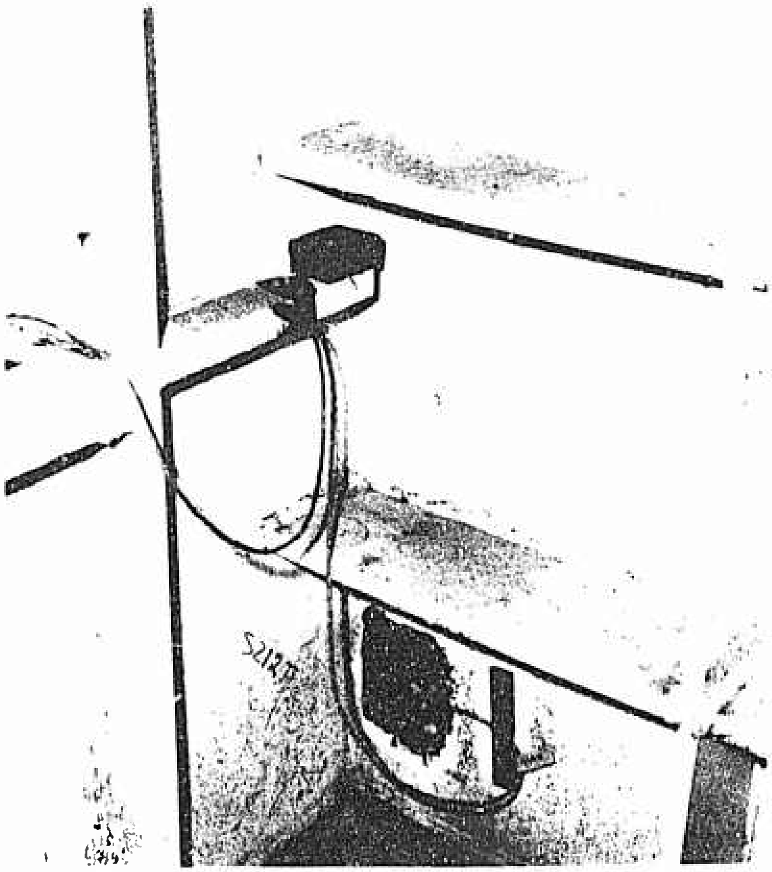

Fig. 8 — Typical strain-gage installation S 212 TA viewed from midships, LFSP port side, looking to port

Effects of Measurement Orientation

The variation of peak velocity with location tends to obscure the influence of the other test parameters, so it is convenient to average out this variation when considering the other parameters. On average, the highest peak velocities on the LFSP mounting plane are those measured in the vertical direction, followed by the horizontal-parallel and, finally, the horizontal-transverse components. For a 45-ft standoff, these (average) peaks are in the ratio 1:0.7:0.3. A similar relation is found on the shell plating, where the corresponding ratio is 1:0.5:0.3.

Effects of Charge Standoff

Standoff is the test variable used to control the severity of shocks on the LFSP. The principal effect of increasing standoff is a smooth decrease in the peak velocities, fairly rapid at first, then becoming more gradual. The decline of peak velocities in the horizontal directions is slightly less pronounced than that in the vertical, so that the ratio of the

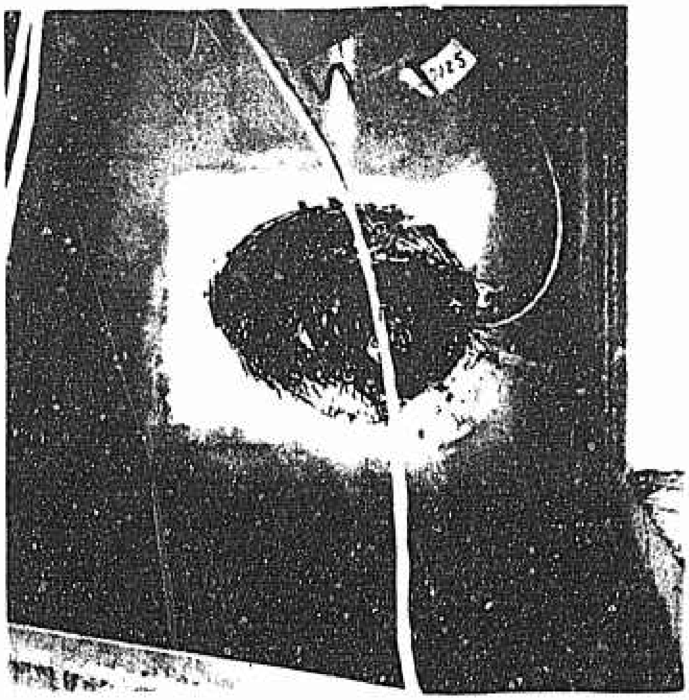

Fig. 9 — Typical strain-gage installation: S 216 T viewed from midships, LFSP port side, looking forward

peaks also changes slightly with standoff. As noted above, at a 45-ft standoff distance the ratio is 1:0.7:0.3, whereas at 120-ft standoff it is 1:0.75:0.4 (Figs. 14, 15).

Effects of Charge Orientation

The only significant effect of charge orientation (end shot vs side shot) is to interchange the characteristics of the motions in the athwartships and fore-and-aft directions. The shape and magnitude of the velocity waveforms in these directions are determined by which direction is parallel to the plan line of the charge and which is perpendicular to it. It would also be anticipated that the (average) peak velocities would be slightly lower for an end shot than for a side shot, and such a tendency can be detected. However, the difference is relatively small.

Effects of Test-Load Weight

The weight of the test item influences the shock environment in two main ways. First, the total weight installed in the LFSP changes its draft, which changes the test geometry and thus the shock energy imparted to the LFSP. The effect is in the direction of less severe shock for greater loads. The more important influence is the greater reaction of more massive test items back upon the LFSP, reducing the significant components of its shock motion. For motion in the vertical direction, the decrease from increased load is fairly sizable, but there is no consistent effect in the horizontal directions.

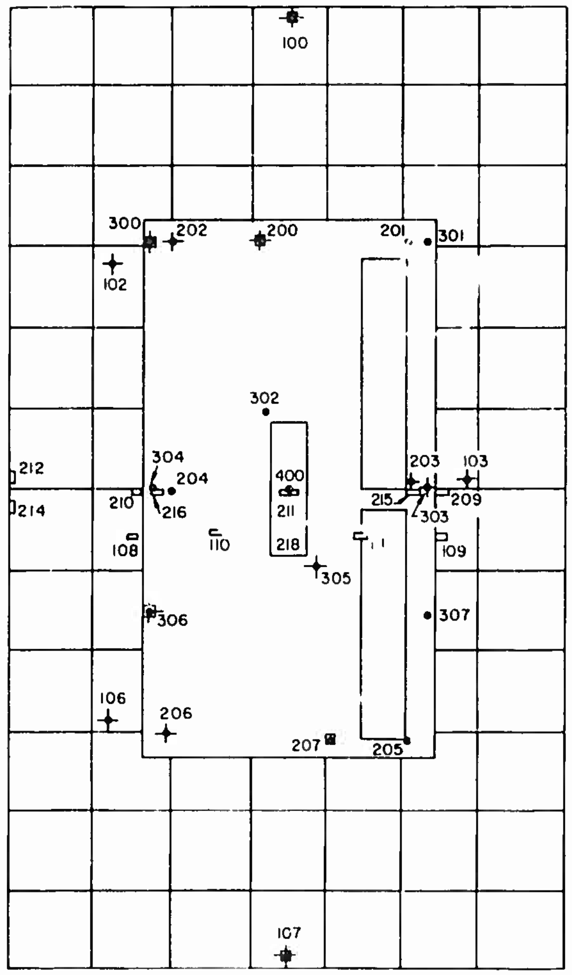

Fig. 10 — Schematic layout of transducer locations. Circles indicate transducers oriented for measurement in the vertical direction, crosses for athwartship, and boxes for fore-and-aft.

Load Velocity Waveforms

The load (FSP) velocity waveforms do not show the characteristics of a lumped-mass and spring combination, but are primarily determined by the local structure of the FSP. This is hardly surprising in view of the stiffness and complexity of the system: the fundamental free-free beam mode of the FSP itself is around 120 Hz, while the frequency of its total mass lumped on the total spring of the mounting plates would be about 300 Hz (240 Hz with added water). The waveforms over FSP bottom cells are somewhat sinusoidal and very similar to those produced at these areas of the FSP when it is operated by itself. The waveforms around the perimeter of the FSP inner bottom, where the connection to the LFSP is stiffest, are similar to the input waveforms, although there are differences indicative of a springier situation. The main differences are that the waveforms from the FSP show an initial approximate half-sine pulse some 10 ms long, followed by a complex wavetrain (amplitude about half that of the initial pulse) with discernible periodicity.

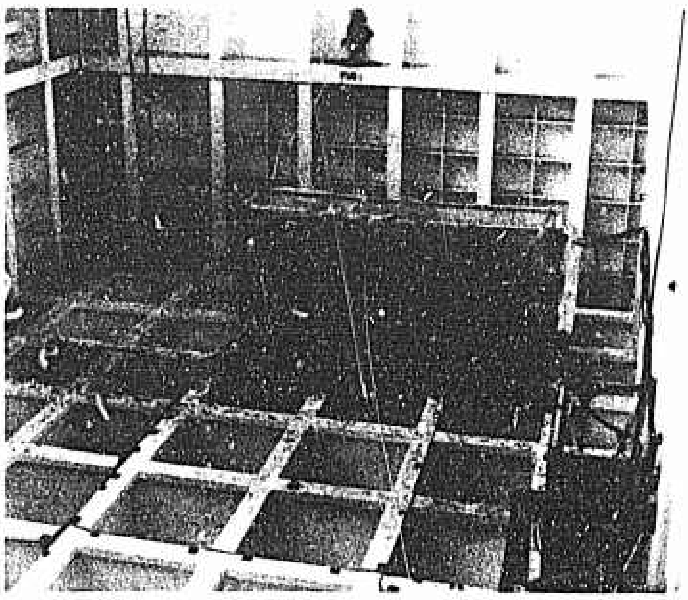

Fig. 11 — Seismically suspended electronics package in the unloaded LFSP, Shots 1 - 6

In the vertical direction, peak velocities vary widely over the load, the greatest being about 2.5 times the smallest; the average is 1.5 times the corresponding average for the inputs. The peak velocities in the two horizontal directions have much less variation over the load and average nearly the same as the inputs. The ratio of the average peak velocities in the three component directions is 1:0.45:0.15 (vertical:horizontal-parallel:horizontal-transverse) (Fig. 16).

The FSP velocities are affected by changes in test conditions in substantially the same way as the input velocities. Increasing standoff causes smoothly decreasing peak load velocity. Increase in load weight decreases peak load velocities in all three directions, but most in the vertical. Changing the charge orientation has a more complicated effect on load velocities than on input velocities. Primarily, the effect is that of interchanging the characters of the athwartship and fore-and-aft velocities, but the average peak fore-and-aft velocity for an end shot is noticeably lower than the average peak athwartship for a side shot (since the athwartship stiffness of the mounting plates is substantially greater than the fore-and-aft stiffness of the gussets), and the average peak vertical velocity is consistently lower for end shots than for side shots.

SDOF System Response Waveforms

The SDOF system was one of several designed by NSRDC for installation on board the ex-USS *Atlanta* for Operation Sailor Hat. Measurements on similar systems during Operations Sailor Hat and Dive Under, Phase I, vertified that the most prominent mode

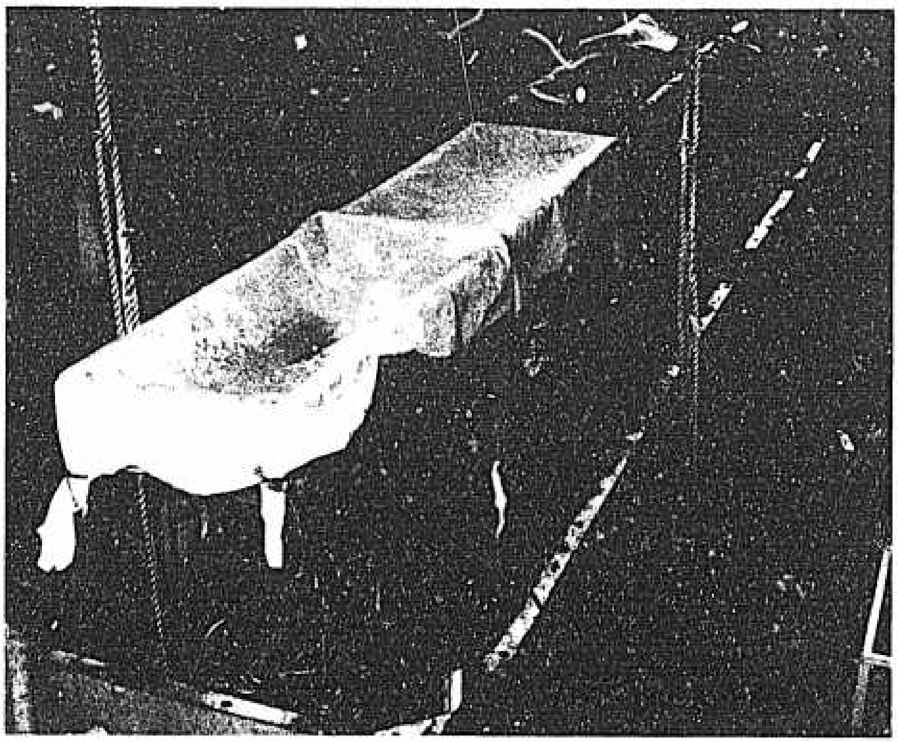

Fig. 12 — Electronics packages mounted in the FSP for Shots 7 - 14

in the response was that of simple vertical translation, at a frequency of 30 Hz. This is true in the present instance, also. The motion of the mass block is a well-sustained sinusoid at an average frequency of 29.4 Hz. The acceleration waveform carries some high-frequency hash for the first couple of cycles, while the velocity and displacement waveforms, integrated from the acceleration, are smooth throughout. Peak responses of the SDOF are listed in Table 2.

Reproducibility

Two successive shots of the series (Shots 12 and 13 of Table 1) were conducted under identical test conditions: 45-ft standoff, port side, 176, 900-lb load. The agreement between peak velocities measured for these shots was quite good. The vertical peaks averaged over the LFSP mounting plane were 10% lower for Shot 12 than for Shot 13, and a similar average for athwartship peaks was 4% lower for Shot 12. The fore-and-aft variation is greater, but the single peak velocity measured in this direction for Shot 12 seems anomalously low. The agreement between the averaged peak load velocities is even better than for the mounting plane.

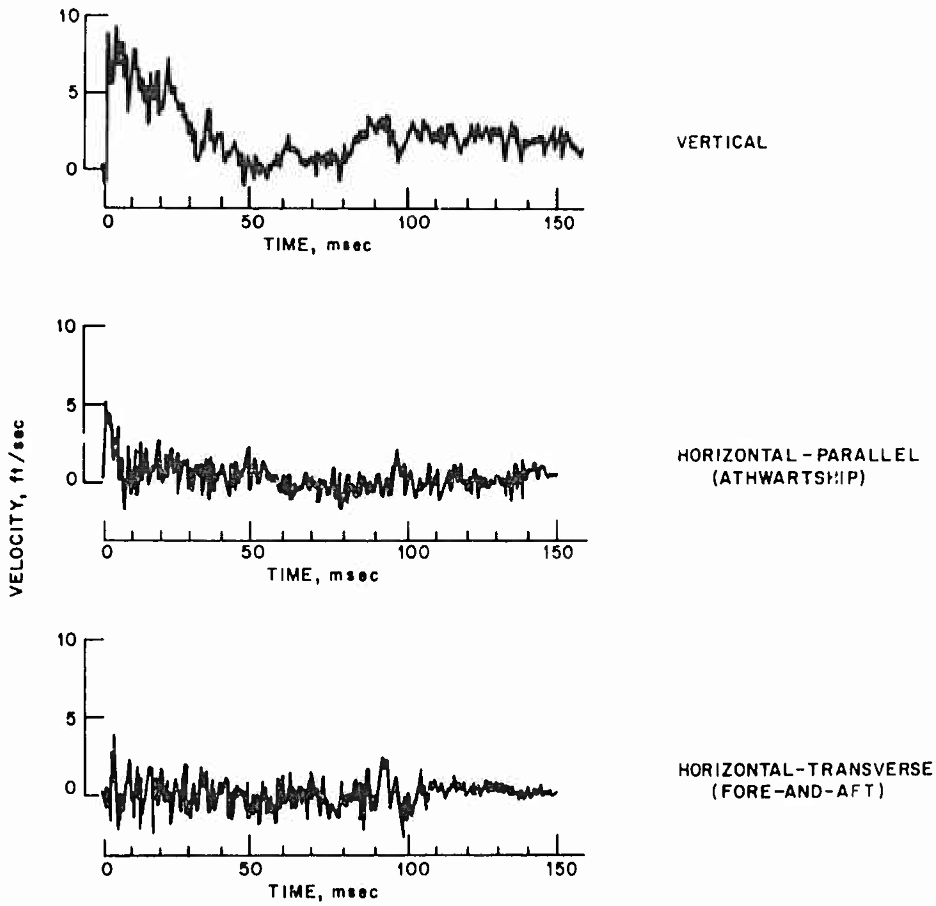

Fig. 13 — Typical velocity waveforms from a portside shot (Shot 9) at 45-ft standoff

SHOCK SPECTRA AND DESIGN SHOCK SPECTRA

Details of the waveforms of motions associated with shipboard and similar environments are highly mutable. Even in the simplest cases, in which a rigid, deadweight load is attached elastically to a rigid shock machine,* small changes in the magnitude or phase of high-frequency components may suffice to render two waveforms completely different to the eye, while they are in fact completely equivalent in ability to cause damage. Conversely, waveforms which have some similarity in appearance may have widely differing damage potentials. Even the peak velocity, a reasonably reproducible parameter indicative of the general severity of a shock environment, may not give a good measure of these aspects of the motion which do damage. In general, the shock spectrum [5] is to be preferred over waveform-related parameters as a measure of shock severity. In essence, it describes the effect of a shock motion and so provides a means for comparing motions with waveforms of different types as well as different specimens of a single type. As normally defined, the shock spectrum of a motion is the graph of the maximum relative displacements of a set of massless linear harmonic oscillators excited by the motion,

*For example, the calibration tests of the LWSM and MWSM [2].

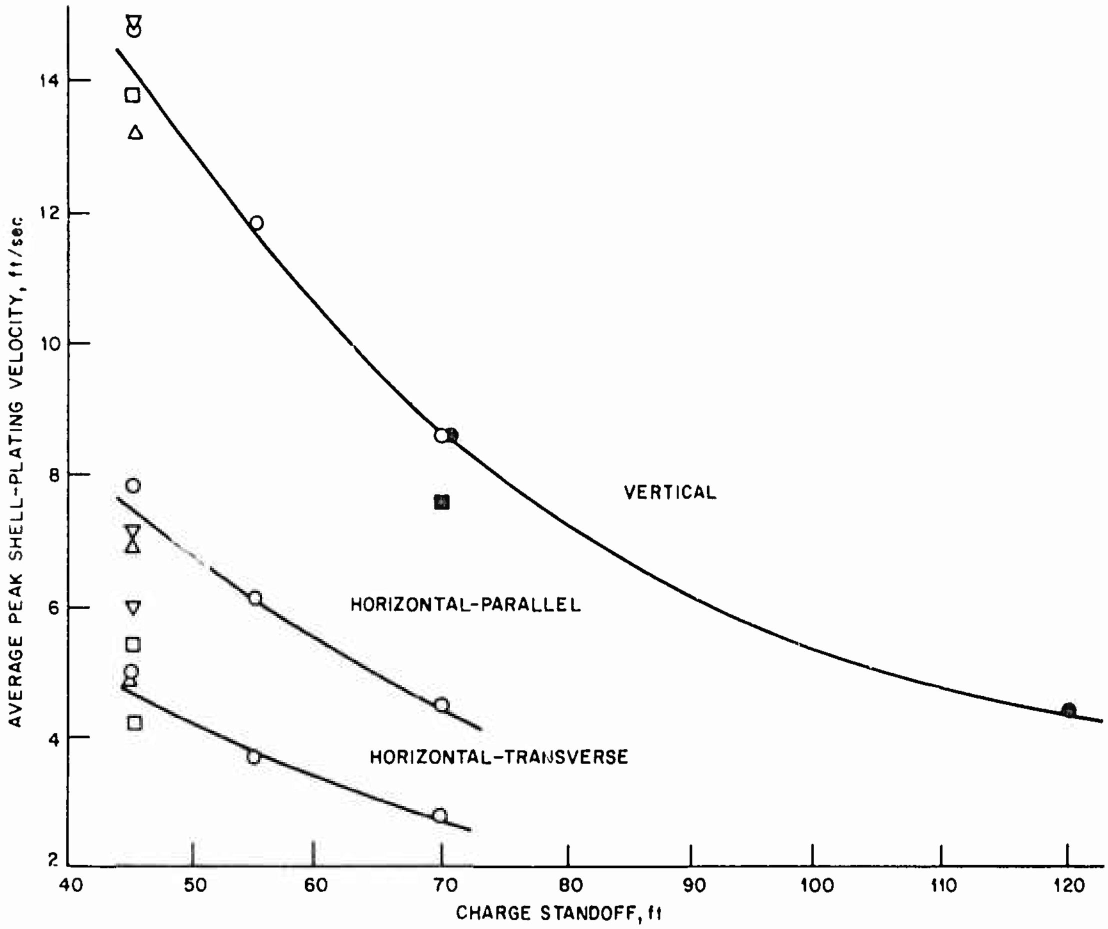

Fig. 14 — Variation of peak velocity (averaged over the LFSP shell-plating) with standoff

○ no added load, portside shot
□ no added load, aft-end shot
▽ no added load, stbd-side shot
△ no added load, forward-end shot
○ 112.6×10^3 lb, portside shot
□ 176.9×10^3 lb, portside shot

plotted as a function of oscillator frequency.* The shock spectrum so defined is also called the maximax or overall, shock spectrum. An important subspecies of shock spectrum is the residual shock spectrum. This is defined similarly to the maximax spectrum, but the maximum relative displacements that occur after the input motion has ceased are plotted, rather than the maxima at any time. The important information in the shock spectrum of an input motion to an equipment item is in the values of the (maximax) shock spectrum at the item's fixed-base natural frequencies, since the (linear, elastic) item

*As a graphical convenience, the product of each oscillator's maximum relative displacement and its radian frequency, rather than just its maximum relative displacement, may be plotted against the oscillator frequency. This has the advantage of being a relatively flat curve, while the graph of displacement only drops off very sharply with increasing frequency. Moreover, it is legitimate to interpret such a graph as showing, for each frequency, the magnitude of a step change of velocity that would cause the same maximum relative displacement (of a SDOF having that frequency) that the actual motion would cause.

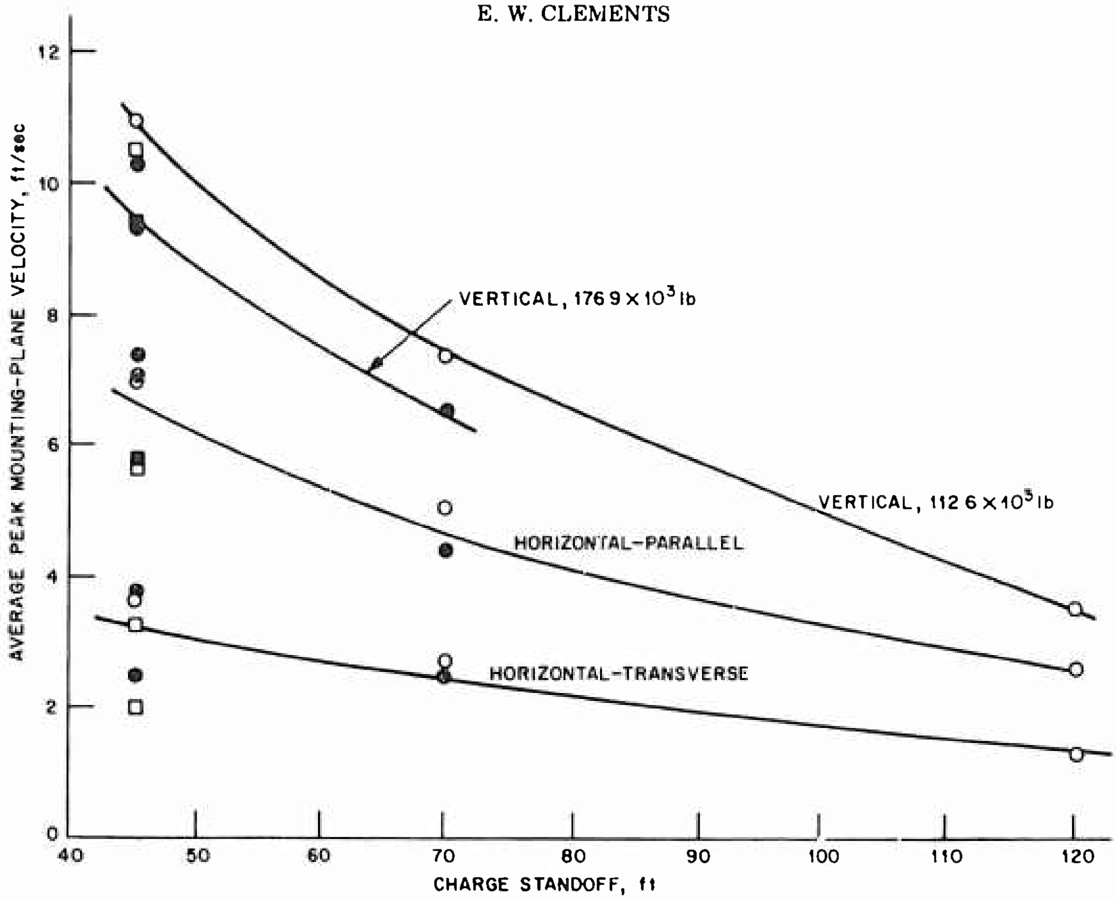

Fig. 15 — Variation of peak velocity (averaged over the LFSP mounting plane) with standoff

○ 112.6×10^3 lb load, portside shot
□ 112.6×10^3 lb load, aft-end shot
○ 176.9×10^3 lb load, portside shot
□ 176.9×10^3 lb load, aft-end shot

must respond in its normal modes. If these frequencies are unknown, they may be estimated from the residual shock spectrum. In responding to components at these frequencies, the item exerts a vibration-absorbing action for them, and dips appear in the residual shock spectrum at frequencies close to the fixed-base natural frequencies of the item. The corresponding values of the maximax spectrum give a measure of the damage potential of the motion so far as the item is concerned and, consequently, a basis for comparing shock motions. For each mode, the shock-spectrum value may be regarded as the value of a velocity step input equivalent to the actual motion.

The design shock spectrum presents such equivalent inputs as functions of modal frequency and modal weight. For lightweight modes, the design shock-spectrum curve giving the dependence of shock spectrum value on modal frequency falls in three contiguous segments. The first segment, at very low frequencies, is a constant-deflection line at the value of the peak displacement involved in the shock motion; the second, at moderately low frequencies, is a constant-velocity line; the third, at high frequencies, is a constant-acceleration line at the value of the highest acceleration involved in the shock motion. Design shock spectra for shipboard structures are based on data derived from

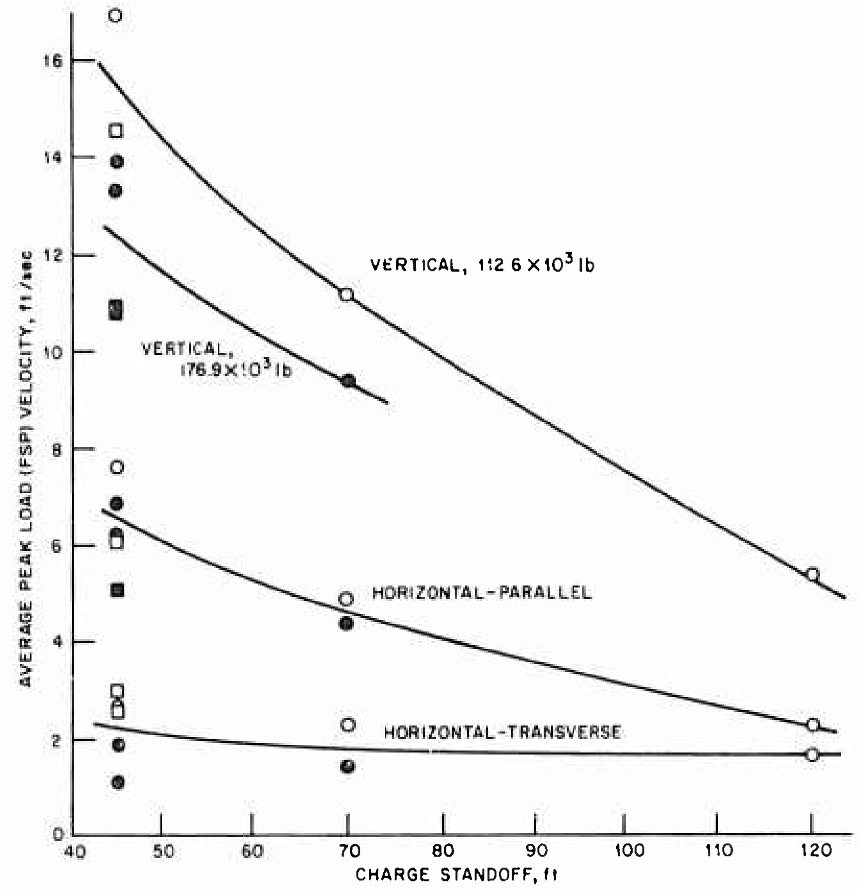

Fig. 16 — Variation of peak velocity (averaged over the load) with standoff

○ 112.6×10^3 lb load, portside shot
□ 112.6×10^3 lb load, aft-end shot
○ 176.9×10^3 lb load, portside shot
□ 176.9×10^3 lb load, aft-end shot

many ships of different types and sizes and may be regarded as describing the conditions existing on some representative ship model and attack situation. This then is a standard combination of masses and springs to which the structure being designed is to be attached, and the ensemble is to be excited by an incoming pressure wave of some standard value and waveform. Under these circumstances the waveform of the motion input to the structure will be influenced by the modal weight. This is accounted for by specifying variations in the values of deflection, velocity, and acceleration, with corresponding variations in the frequencies at which the transitions between the three basic regions of the design shock spectrum occur.

LFSP SHOCK SPECTRA

A typical shock spectrum (for vertical motion) from the LFSP is shown in Fig. 17. The velocity shock region of the design shock spectrum (Fig. 13) is obtained from such individual spectra by noting the values of the maximax spectra at the first few frequencies where dips occur in the residuals. The distribution of shock spectrum values over the

Table 2
Single-Degree-of-Freedom System Responses

Shot No.	Near Side	Standoff (ft)	Added Load (10^3 lb)	Peak SDOF Response		
				Acceleration (g)	Velocity (ft/s)	Displacement (in.)
7	Port	120	112.6	45	5.6	0.49
8	Port	70	112.6	63	8.6	1.35
9	Port	45	112.6	88	13.3	2.40
10	Stern	45	112.6	106	11.7	1.96
11	Port	70	176.9	56	8.9	1.47
12	Port	45	176.9	86	13.4	1.88
13	Port	45	176.9	91	14.2	2.07
14	Stern	45	176.9	87	12.0	2.22

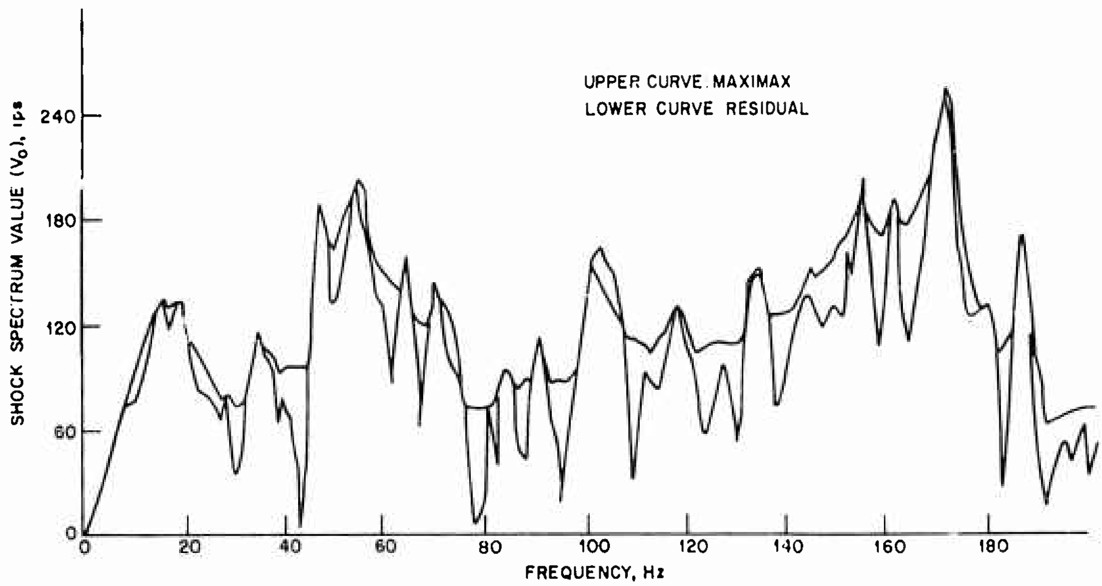

Fig. 17 — Typical shock spectrum for vertical motion at a location on the LFSP mounting plane

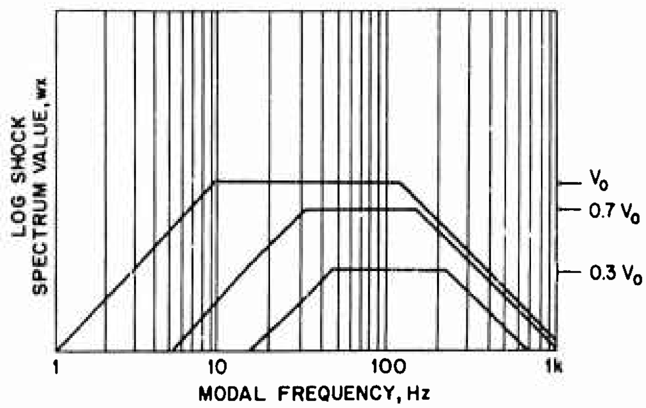

Fig. 18 — Design shock spectra: variation with modal frequency. Spectra from upper to lower curves are for vertical, horizontal-parallel, and horizontal-transverse motions, respectively.

mounting plane of the LFSP has a pattern much like that of the peak velocities. Typically, the shock-spectrum values are somewhat lower than the corresponding peak velocities and show more variation from place to place.

Since shock spectra were obtained only from vertical motions, the design spectra for the horizontal directions were estimated by assuming that their proportions to the vertical components were the same, on average, as their proportions for peak velocity. The acceleration and displacement limits were taken as the slopes of the velocity vs time curves and the peak values of their integrals.

The variation in average shock spectrum value with charge standoff (Fig. 19) follows a noticeably flatter curve than does peak velocity, and the effect of load weight is considerably greater. The curve showing this (Fig. 20) is partially inferred: For each load condition, 80% of the total weight has been assigned to the dominant mode, and the curve has been extended to low modal weights because of the near equality of the average peak velocities on the shell plating for the unloaded and 112, 600-lb load conditions. In theory, this curve should describe an S-shape. The data available appear to indicate the upper inflection of such a shape, and it is hoped that data explicating its course at higher loads will be accumulated during future tests. Such data may also reveal the decrease in corner frequency expected from theoretical considerations but not notable in the present data.

EFFECTS OF SHOCK ON LFSP STRUCTURE

The portion of the test series without added load (Shots 1 - 6, Table 1) served as a structural test for the LFSP. The shortest standoff, 45 ft, was selected as presenting the most severe environment likely to be required for normal operation. Tests at this standoff were conducted against all sides of the LFSP. Some minor cracking of welds occurred, principally in the secondary reinforcing webs installed around the sides and around the edges of the bottom. These cracks were repaired prior to the installation of the test load, and no cracking resulted from the later shots of the test series.

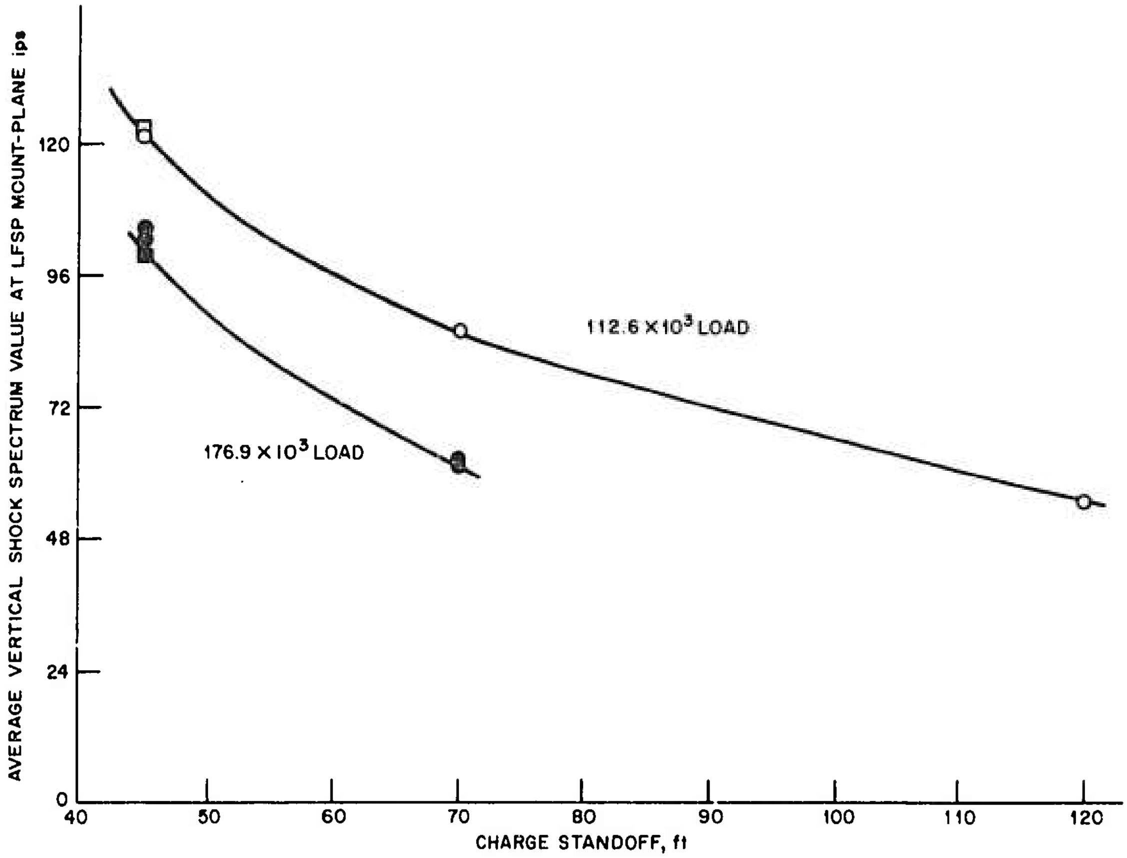

Fig. 19 — Variation in shock spectrum value (average over the LFSP mounting plane) with standoff

○ 112.6 x 10^3 lb load, portside shot
□ 112.6 x 10^3 lb load, aft-end shot
○ 176.9 x 10^3 lb load, portside shot
□ 176.9 x 10^3 lb load, aft-end shot

With one exception the strain-gage records indicate elastic behavior. The exception is on the bottom plating at the cell closest to the charge, where (for 45-ft standoff) a permanent set of 100-200 μin/in. may occur. For a given shot geometry, the peak strains are generally higher with the greater load, but the differences are less than those between the two nominally identical shots.

The slight, localized permanent set may be expected to decrease as the material work-hardens, so that, unless operating conditions are more severe than those of this test series, the LFSP should prove an essentially elastic test device whose characteristics are little affected by normal use.

CONCLUSION

With the addition of the LFSP to the Navy's shock-testing devices, it is possible to subject test items weighing up to 400,000 lb to simulated shipboard shock. The four devices (LWSM, MWSM, FSP, LFSP) differ greatly in design and operation but are very

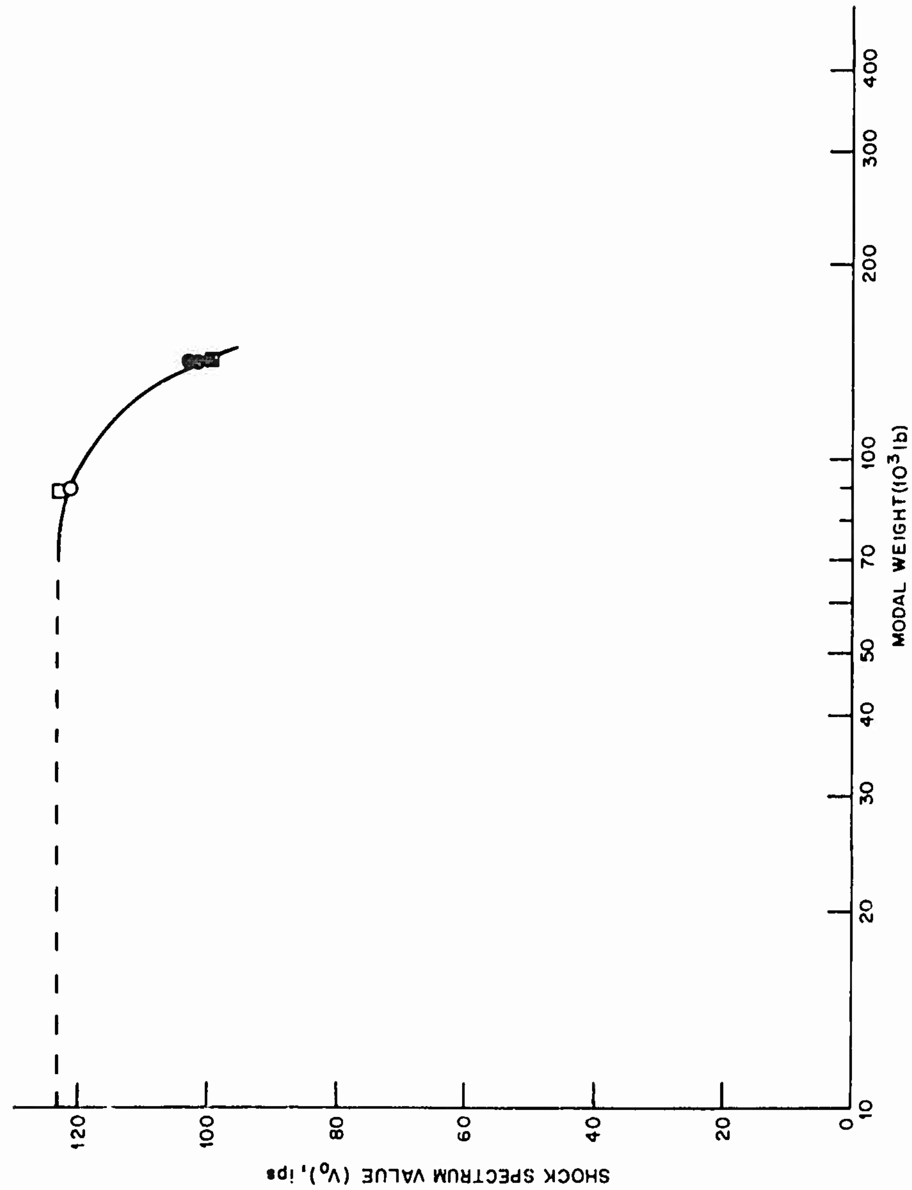

Fig. 20 — Design shock spectrum: variation with modal weight. Charge standoff is 45 ft.

○ 112.6×10^3 lb load, portside shot
□ 112.6×10^3 lb load, aft-end shot
○ 176.9×10^3 lb load, portside shot
□ 176.9×10^3 lb load, aft-end shot

compatible in the essential characteristics of the shock environments they provide to their test loads.

The compatibility of the three previously existing machines has been established by observations over a span of years. This has been done by comparing the kinds and rates of damage occurrence to equipment as well as by comparison of peak velocities, shock-spectrum values, ranges of dominant frequencies, and so on. Statistics on damage relating to the LFSP will have to be accumulated with use. However, the information at hand indicates that it can provide a shock environment equivalent to that of the FSP to a test item at the crossover weight of 40,000 lb. The basis for this equivalence is the shock-spectrum value, similarity of spectral content, and comparability of peak velocity and velocity waveform.

An instruction manual [6] for general operation of the LFSP has been prepared by the West Coast Shock Facility, and standard conditions for Navy acceptance testing will be specified in future editions of MIL-S-901. It is probable that normal operating conditions will be such that the LFSP will be an essentially elastic test machine whose structure and characteristics will change little with use. Additional data would be desirable, particularly concerning the LFSP's behavior with extremely large loads. Such information can be gathered as large items are tested.

ACKNOWLEDGMENTS

The author expresses his gratitude to the members of the LFSP operating team (C. Schrader, S. Giannoccolo, G. Volpe, and S. Vogensen), all of WCSF, and the instrumentation team (C. Cunningham, E. Judd, and C. Lamb of NRL; and T. Saksa and C. Parker of WCSF).

REFERENCES

1. MIL-S-901C (NAVY), "Military Specification. Shock Tests, HI (High-Impact); Shipboard Machinery, Equipment, and Systems, Requirements for," Jan. 15, 1963.

2. E.W. Clements, "Shipboard Shock and Navy Devices for Its Simulation," NRL Report 7396, July 14, 1972.

3. M.W. Oleson, "Components of a New Shock Measurement System," Report of NRL Progress, Oct. 1967, pp. 16-27.

4. M.W. Oleson, "Shock Signal Integrator—Description, Operation and Schematics," NRL Memorandum Report 1903, July 1968.

5. G.J. O'Hara, "Shock Spectra and Design Shock Spectra," NRL Report 5386, Nov. 1959.

6. "Operation Manual for Large Floating Shock Platform (LFSP)," Hunters Point Naval Shipyard Tech. Rept. 10-73, July 1973.

Appendix A
OPERATION OF THE LARGE FLOATING SHOCK PLATFORM (LFSP)

S. Giannoccolo
West Coast Shock Facility

The Large Floating Shock Platform (LFSP) is 50 ft long, 30 ft wide, and designed to shock test equipment weighing up to 400,000 lb. The platform is made of HTS steel and has a 19-ft-high fiber-glass canopy to protect the equipment and instrumentation from water damage caused by the explosive plume.

The LFSP is usually moored at Berth 21 (shock site). Here the equipment to be tested and the required instrumentation is installed onboard. On the day preceding the shot, all the necessary rigging gear is mounted on the platform. On each end of the craft a bridle is installed: one of 1-1/2-in.-diam nylon rope and the other of 5/8-in. steel wire. The instrumentation is checked.

On the day of the shock test, an LCM, a work boat, and a sonar boat are placed in the water. The sonar boat goes across the bay to Alameda Naval Station to pick up the explosive charge for the test, while the LCM, with the assistance of the work boat, moors and tows the LFSP to the staging area (Berth 25), where the final rigging installation takes place. One bridle (5/8-in. steel-wire) is connected to a 1-1/2-in.-diam polypropylene rope approximately 1000 ft long carried by the tow winch of the LCM; the other (1-1/2-in.-diam nylon rope) is secured to the inhaul 3/4-in.-diam steel line of the winch at Berth 25. To this bridle is also attached the firing control and the power-supply lines. These lines are supported by tube floats to minimize tidal current drag on the system and are secured in two clamps at the bridle end and the control station end, where they are tied to a bollard with 2-in. nylon rope.

The instrumentation is checked and calibrated and the firing setup cycled. (Control of firing and system emergency stop are located at the control station on shore).

During the rigging of the LFSP at Berth 25, the explosive charge transported by the sonar boat to the shock site (Berth 21) is armed in a barbette, attached to a float, and lowered into the water by a mobile crane. The float with the suspended charge is then slowly towed by the work boat to the staging area (Berth 25). Float and charge are now attached to the holding pole protruding outboard from the side or from the end of the LFSP.

The sonar boat then starts patrolling the test area to check for the presence of fish; the test is delayed if large schools of fish are in the area.

The LCM tows by paying out the outhaul line and positioning the LFSP 900 ft from Berth 25, until the winch inhaul line on shore is in tension.

The work boat takes the charge out from the side or end of the LFSP to proper standoff and pays out the tension line.

The firing engineer checks the circuits on the LFSP, connects the charge to the firing system, turns on the manual safety switch, and leaves the platform in the sonar boat.

The project engineer is informed from the sonar boat that the test area is clear of fish. After a check of the firing and control circuits in the control station, he starts the countdown and turns on the arming switch. At minus 45 s, the sequence timer is activated.

After shot time, sonar boat personnel inspect for damage to the LFSP and advise if it is all right to retrieve the platform to the staging area by the inhaul winch. The rigging, firing, and power cables are removed. The LCM tows the LFSP from Berth 25 back to the shock site (Berth 21).

During all phases of the operation, a yard tug stands by in the area in case of emergency.

Appendix B
TRANSDUCER TYPES AND LOCATIONS

Each measurement transducer is assigned a gage designator consisting of an alphabetic prefix indicating the type of transducer, a number showing its approximate location, and an alphabetic suffix giving the orientation of its measurement axis. The basic scheme was as follows:

Prefix: A—accelerometer
AV—integrated accelerometer
S—strain-gage bridge

Number: 100-199—LFSP shell plating
200-299—LFSP mounting plane and load (FSP) mounting plates
300-399—FSP deck
400-499—SDOF mass
Within each century, numbers are assigned counting from bow to stern; odd numbers to starboard, and even to port, of LFSP centerline.

Suffix: A—athwartship
F—fore-and-aft
V—vertical
T—total strain

The measurement transducers and their locations and purposes are listed in Table B1. Locations are specified by three position numbers: x, y, and z. The coding for these is listed below.

x, fore-and-aft coordinate, scaled 0 to 12

Number of LFSP athwartship stiffener, counting from forward (bow = 0) to aft (stern 2=12).

y, athwartship coordinate, scaled 0 to 7

Number of LFSP longitudinal stiffener, counting from port (side = 0) to starboard (side = 7).

z, vertical coordinate, scaled 1 to 6, locations as follows:

1 - LFSP bottom shell plating

2 - Halfway up LFSP stiffener

3 - Top of LFSP stiffener (LFSP mounting plane)

4 - Halfway up FSP (load) mounting plate

5 - FSP deck

6 - Top of SDOF mass.

(side = 0) to starboard (side = 7).

Table B1
Measurement Transducers

Purpose	Location			Gage Designator
	z	y	x	
Mapping LFSP motion	1	3.5	0	AV 100 V,A,F
Mapping LFSP motion	1	1	3	AV 102 V,A,F
Mapping LFSP motion	1	6	6	AV 103 V,A
Mapping LFSP motion	1	1	9	AV 106 V,A
Mapping LFSP motion	1	3.5	12	AV 107 V,A,F
Mapping LFSP motion; input to FSP	3	3	3	AV 200 V,A,F
Mapping LFSP motion; input to FSP	3	5	3	AV 201 V
Mapping LFSP motion; input to FSP	3	2	3	AV 202 V,A
Mapping LFSP motion; input to FSP	3	5	6	AV 203, V,A
Mapping LFSP motion; input to FSP	3	2	6	AV 204 V
Mapping LFSP motion; input to FSP	3	5	9	AV 205 V
Mapping LFSP motion; input to FSP	3	2	9	AV 206 V,A
Mapping LFSP motion; input to FSP	3	1	9	AV 207 V,F
Bottom deformation	1	1.5	6.5	S 108 T
Bottom deformation	1	5.5	6.5	S 109 T
Bottom deformation	1	2.5	6.5	S 110 T
Bottom deformation	1	4.5	6.5	S 111 T
Stiffener deformation	2	5	6	S 209 T
Stiffener deformation	2	2	6	S 210 T
Stiffener deformation	2	3.5	6	S 211 T
Port-side deformation	2	0	6	S 212 TA
Port-side deformation	2	0	6	S 214 TA
FSP mounting plate deformation	4	2	6	S 215 T
FSP mounting plate deformation	4	3.5	6	S 216 T
FSP mounting plate deformation	4	5	6	S 218 T
Mapping FSP motion	5	Port	Forward corner of FSP	AV 300 V,A,F
Mapping FSP motion	5	Stbd	Forward corner of FSP	AV 301 V
Mapping FSP motion; SDOF input	5	Port	Forward corner SDOF fndn	AV 302 V
Mapping FSP motion	5	Stbd	Midships FSP	AV 303 V,A
Mapping FSP motion	5	Port	Midships FSP	AV 304 V
Mapping FSP motion; SDOF input	5	Stbd	Aft corner SDOF foundation	AV 305 V,A
Mapping FSP motion	5	Port	Center of free span FSP	AV 306 V,A,F
Mapping FSP motion	5	Stbd	Center of free span FSP	AV 307 V
SDOF response	6	Midships	Centerline of SDOF mass	A 400 V

Appendix C
SYNOPTIC DATA

Tables C1-C8 summarize all data obtained from the tests. The summary shows velocity, displacement, design-spectrum value, and acceleration obtained by playing back and analyzing tape-recorded signals. Lack of an entry means that no measurement was made at that position for that shot. Adjusted averages are those averages compensated for missing readings by assuming that their contributions to the overall averages are the same as for shots of similar geometry. (Appendix B explains the alphanumeric nomenclature for gage designators.)

Table C1
Peak Velocities (ft/s), LFSP Shell Plating

Gage Designator	Shot No.										
	1	2	3	4	5	6	7	8	9	10	11
AV 100 V	6.0	8.0	12.4	7.6	13.1	13.7					
AV 102 V	11.8	16.0	19.1	12.2	18.3	19.0		10.4			9.4
AV 103 V	11.5	13.6	18.4	14.4			4.7	6.3			6.4
AV 106 V	11.0	15.8	18.8	19.8	19.6	11.9					
AV 107 V	2.6	5.2	5.3	15.2	8.6	8.1	3.3	9.1			7.2
Adj Av	8.6	11.8	14.8	13.8	14.9	13.2	4.4	8.6			7.6
AV 100 A	3.8	5.1	5.3	2.8	6.1	4.7					
AV 102 A	5.4	7.2	9.5	3.2	6.2	6.4					
AV 103 A	4.7	5.9	8.6	3.2	8.2	4.7					
AV 106 A	5.8	8.7	11.3	7.5	7.6	4.4					
AV 107 A	2.9	3.8	4.5								
Adj Av	4.5	6.1	7.8	4.2	7.0	5.0					
AV 100 F	3.2	4.7	6.3	6.6	6.9	7.6					
AV 107 F	2.3	2.7	2.7	4.2	5.2	6.2					
Av	2.8	3.7	5.0	5.4	6.1	6.9					

Table C2
Peak Velocities (ft/s), LFSP Mounting Plane

Gage Designator	Shot No.							
	7	8	9	10	11	12	13	14
AV 200 V	3.7	7.2	11.4	8.0	5.9	8.5	9.4	8.0
AV 201 V		5.8	7.7	8.4	5.0	7.3	7.3	6.5
AV 202 V	4.1	8.4	14.4	8.0	7.5	11.2	13.4	6.6
AV 203 V	3.2	6.6	8.2	9.5	6.4	8.9	9.8	7.9
AV 204 V	4.6	9.6	13.8		9.2	12.3	13.1	8.7
AV 205 V	3.0	5.7	8.4	13.4	4.9	7.2	7.6	11.6
AV 206 V	4.0	9.0	13.2	12.1	7.6	11.1	13.0	11.3
AV 207 V	3.3	6.4	10.7	14.4	5.9	8.0	8.9	14.2
Adj Av	3.5	7.3	11.0	10.5	6.6	9.3	10.3	9.4
AV 200 A	2.1	4.1	5.4	3.0	4.0	5.4	5.8	1.6
AV 202 A	3.8	6.4	8.7	3.3	6.2	8.6	9.2	1.9
AV 203 A	1.7	3.4		1.3	1.4	4.9		
AV 206 A	3.0	6.3	9.5	5.4	6.0	9.6	9.7	3.8
Adj Av	2.6	5.0	7.0	3.2	4.4	7.1	7.4	2.0
AV 200 F	1.4			3.8	3.0		3.9	4.0
AV 207 F	1.2	2.4	3.4	7.5	2.4	2.4	3.5	7.6
Adj Av	1.3	2.5	3.6	5.7	2.7	2.5	3.7	5.8

Table C3
Peak Velocities (ft/s), Load (FSP) Response

Gage Designator	Shot No.							
	7	8	9	10	11	12	13	14
AV 300 V	4.8	12.9	18.8	10.3	11.7	16.2	17.2	7.9
AV 301 V	3.7	7.0	9.6	11.3	7.0	8.6	9.0	7.5
AV 302 V	7.2	14.4	21.0	17.0	9.0	13.4	14.1	10.9
AV 303 V	4.0	7.3		9.3	6.4	9.4	9.8	7.3
AV 304 V	7.3	15.2	24.6	16.1	12.6	19.1	20.2	12.7
AV 305 V	5.3				9.8			18.2
AV 306 V	6.0	13.1	21.3	14.7	11.1	16.0	16.7	12.0
AV 307 V	4.5	8.1	10.2	12.8	7.0	9.6	9.6	10.2
Adj Av	5.4	11.2	16.9	14.5	9.3	13.3	13.9	10.8
AV 300 A		5.0					7.5	3.1
AV 303 A	2.3	5.1	7.7	3.0	4.3	6.3	7.3	1.5
AV 305 A	2.3	5.0	8.2	2.4	3.9	6.1	6.5	3.6
AV 306 A	2.0	4.5	6.8	2.3	4.6	6.0	6.2	1.8
Adj Av	2.2	4.9	7.6	2.6	4.3	6.2	6.9	2.5
AV 300 F	2.3			6.3	1.4		2.4	4.9
AV 306 F	0.9	1.3	1.5	5.7	1.4	1.1	1.4	5.2
Adj Av	1.6	2.2	2.6	6.0	1.4	1.1	1.9	5.1

Table C4
Peak Displacements (in.), LFSP Mounting Plane

Gage Designator	Shot No.							
	7	8	9	10	11	12	13	14
AV 200 V	0.31	1.1	2.1	0.96	1.1	1.6	2.1	0.97
AV 201 V		0.90	1.5	0.59	0.79	1.5	1.7	0.94
AV 202 V	0.31	1.2		0.99	1.4	2.0	3.3	0.95
AV 203 V	0.32	0.66	1.2	1.6	0.90	1.5	1.8	1.8
AV 204 V	0.30	1.6	3.0		1.5	3.3	3.8	2.2
AV 205 V	0.21	0.84	1.7	3.1	0.86	1.7	1.9	2.9
AV 206 V	0.35	1.2	2.4	2.3	1.2	2.3	3.0	2.7
AV 207 V	0.33	1.1	2.1	3.5	1.1	2.2	2.4	3.2
Adj Av	0.30	1.1	2.0	1.9	1.1	2.0	2.5	2.0
AV 200 A	0.05	0.19	0.34	0.05	0.20	0.30	0.66	—*
AV 202 A	0.05	0.25	0.53	0.05	0.30	0.20	0.97	—
AV 203 A	0.05	0.15		0.15	0.19	0.39		
AV 206 A	0.05	0.11	0.51	0.15	0.20	0.55	0.45	0.05
Adj Av	0.05	0.18	0.44	0.10	0.11	0.36	0.71	0.02
AV 200 F	—			0.45	0.05		0.10	0.41
AV 207 F	—	0.05	0.05	0.15	0.05	0.15	0.10	0.15
Av	—	0.05	0.05	0.30	0.05	0.15	0.10	0.28

*Dashes indicate negligibly small displacement.

Table C5
Peak Displacements (in.), Load (FSP) Response

Gage Designator	Shot No.							
	7	8	9	10	11	12	13	14
AV 300 V	0.27	1.0	2.1	0.85	1.2	2.6	2.5	0.94
AV 301 V	0.26	0.88	1.5	0.97	1.9	1.5	2.1	1.0
AV 302 V	0.31	1.3	2.1	1.5	1.2	1.9	2.6	1.4
AV 303 V	0.25	0.72	1.4	1.7	0.80	1.6	1.7	1.8
AV 304 V	0.36	1.6	4.0	2.4	1.9	4.2	4.1	2.7
AV 305 V	0.25				1.5			2.3
AV 306 V	0.45	1.5	3.8	2.8	1.5	3.1	3.4	2.7
AV 307 V	0.26	0.86	1.7	2.2	0.85	1.7	1.8	2.3
Adj Av	0.30	1.1	2.3	1.8	1.3	2.4	2.6	1.9
AV 300 A		0.25					0.90	0.13
AV 303 A	0.15	0.25	0.68	0.15	0.30	0.44	0.47	0.10
AV 305 A	0.16		0.55	0.10	0.25	0.39	0.56	0.36
AV 306 A	0.15		0.60	0.20	0.25	0.70	0.35	0.05
Adj Av	0.15	0.25	0.61	0.15	0.27	0.51	0.57	0.16
AV 300 F	—*			0.56	0.04		0.29	0.59
AV 306 F	—	—	0.10	0.49	0.05	—	0.05	0.69
Av	—	—	0.10	0.52	0.04	—	0.17	0.64

*Dashes indicate negligibly small displacement.

Table C6
Design Shock-Spectrum Values (ft/s), LFSP Mounting Plane

Gage Designator	Shot No.							
	7	8	9	10	11	12	13	14
AV 200 V	5.4	6.4	10.6	12.4	5.6		7.8	7.3
AV 201 V		7.2	8.8	11.8			9.6	6.6
AV 202 V	4.8	9.1	13.6	10.1	4.2		10.3	7.0
AV 203 V	5.1	7.6	11.8	7.3		7.6	7.8	7.5
AV 204 V	3.8	7.9	5.8		4.8	6.6	6.5	
AV 205 V	5.2	6.3			4.8	6.6		8.3
AV 206 V	3.9	7.0		9.6		9.4	8.9	8.2
AV 207 V	4.1	5.1		10.1	6.4	12.8	8.4	13.3
Adj Av	4.6	7.1	9.4	10.2	6.2	9.0	8.3	8.4

Table C7
Slope Accelerations (g), LFSP Mounting Plane

Gage Designator		Shot No.			
	9	10	12	13	14
AV 200 V	200	310	130	160	210
AV 201 V	200	200	160	160	200
AV 202 V	320	140	300	310	150
AV 203 V	210	610	120	210	160
AV 204 V	160		310	310	210
AV 205 V	150	120	100	310	210
AV 206 V	150	160	210	160	330
AV 207 V	300	210	160	100	300
Av.	210	250	210	210	220
AV 200 A	200	100	210	160	160
AV 202 A	200	100	210	320	160
AV 203 A			150		
AV 206 A	240	100	210	310	130
Adj Av	210	100	190	240	140

Table C7—Continued

Gage Designator	Shot No.				
	9	10	12	13	14
AV 200 F		100		90	130
AV 207 F	120	200	100	80	200
Av.	120	150	100	85	165

Table C8
Peak Strains (μin/in.), LFSP and FSP Mounting Plate

Gage Designator	Shot No.							
	7	8	9	10	11	12	13	14
S 108 T	830	1780	2150	500	1780	2290	2560	710
S 109 T	250	570	800	880	590	900	890	960
S 110 T	520	980	1560	380	1100	1570	1680	410
S 111 T	260	490	740	400	580	760	910	380
S 209 T	160			320	230		300	410
S 210 T	300				410		680	510
S 211 T	170			1080	310		390	1310
S 212 TA	200			230	420		540	200
S 214 TA	300			240	540		860	180
S 215 T	340				430		650	750
S 216 T	320			490	670		1110	580
S 218 T	190			1030	530		870	1000